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Reference Sound Pressure for Navy Noise Measurements

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RECOMMENDATION

For reasons set forth below, it is recommended that for sound pressure level the reference sound pressure be 0.0002 microbar, except that in the calibration of transducers the reference pressure may be 1 microbar. This applies regardless of the medium in which the sound exists, whether in air or water. The practice should be continued of stating the reference quantity at least once in each written report.

HISTORY

When the New York Noise Abatement Commission was appointed in 1929 "to study city noise and map out the means of abating it" there was already a practice¹⁻³ of several years' standing for measuring noise by a technique which depended upon the ear. For the New York survey, both "deafening" tests and purely physical measurements were made.⁶ It is thus quite understandable that equipment for the latter was calibrated in such a way as to give results that presumably could be compared directly with the former.

There was disagreement^{4,5}, however, on how the zero on the sound meter should be established; among those concerned with the practical problems of constructing noise meters^{7,8,10} there was considerable interest in a reference pressure of 0.001 dyne/cm². When the American Standards Association organized Sectional Committee Z24 for acoustics, in 1932, a subcommittee was named at once to consider the problems of noise measurement. Its deliberations were strongly influenced by a desire⁹ to associate the decibel with a quantity like power, and a sound intensity of 10⁻¹⁶ watt/cm² was chosen^{11,13} as the primary

¹Numbers refer to the annotated bibliography in Appendix A.

reference quantity. Then, for consistency in almost normal air, 0.0002 dyne/cm^2 and 0.00005 cm/sec were named ¹³ as the reference quantities for sound pressure level and velocity level respectively.

International discussion ¹⁵ of standardization of that period was phrased in terms of both a reference intensity and a reference pressure. However, the German standard ²⁰ for the sound-level meter that stemmed from these discussions was based solely on a reference pressure of $2 \times 10^{-4} \text{ dyne/cm}^2$, and when an international standard ⁴⁷ was finally adopted sound pressure level was given first place.

When E. J. Abbott reviewed ¹² the numerous scales in use in 1935 for noise measurements and calculations, his appraisal of the advantages of sound intensity were bluntly "None." He personally favored 0.001 or 0.01 dyne/cm^2 as the reference; in retrospect it seems that many of the present differences of opinion would never have arisen had his views been adopted. Fortunately, his ideas were accepted by a change of the reference quantity specified for the sound-level meter from an intensity ¹⁴ to a sound pressure ²². By 1940, standardization of the reference pressure for sound-level meters was almost ¹⁸ an accomplished fact, but problems ^{16,17} of attaining this calibration still remained.

When the underwater noises of ships and mine-sweeping noise makers were measured ¹⁹ for the U. S. Navy in 1941, graphs in the reports were simply marked "sound pressure level in decibels." It was not necessary to state the reference pressure because, in compliance with Definition 1.26 of American Tentative Standard Acoustical Terminology Z24.1-1936 then in effect, "Unless otherwise specified, the reference pressure is understood to be $0.0002 \text{ dyne per square centimeter}$." This same statement was reiterated in the revised American Standard Acoustical Terminology Z24.1-1942.

During World War II most underwater noise measurements of sound pressure level in the USA were reported ²¹ with 0.0002 dyne/cm^2 as the reference pressure, and in due course the same reference pressure was offered ^{23,24} for transducer calibration. For the latter purpose, however, 1 dyne/cm^2 was adopted ^{25,26} and, by sleight-of-hand ²⁷⁻³² disgraceful to a scientific community, this reference pressure was later cited ³³ as "preferred" by the U. S. Navy for all underwater sound measurements.

When standardization activity was resumed in 1946 the desirability of a single reference pressure for all media was recognized.³⁴ No agreement on a specific reference pressure could be reached, however, so that when American Standard Acoustical Terminology, Z24.1-1951 was finally issued it included the requirement: "The reference pressure shall be explicitly stated." Thus it is today that carefully prepared graphs and tables of noise measurements (whether in air or water) list the reference pressure.

The selection of a reference pressure has, again and again, been confused with the selection of a reference intensity. It is possible to choose reference quantities so that, in a free progressive wave in any one medium, sound pressure level in decibels will be numerically equal to intensity level. Most sound waves in enclosures are not free progressive, and even though the warning has been reiterated over the years that the sound pressure level at a given point is not in general equal to the intensity level at that same point, some texts³⁵ have tended to associate sound pressure level in decibels with intensity level so closely that the distinction tends to be lost; the idea of the decibel is often introduced⁴⁵ in connection with intensity. It is the present writer's opinion that such frustrating complications will disappear as soon as a clear distinction is drawn and maintained between sound pressure and intensity. The former is usually measured--very rarely the latter.

Some eight years ago a collective effort in the Bureau of Ships led to an instruction^{36,37} for the use of 0.0002 dyne/cm^2 as the reference pressure for noise measurements in either air or water. For reasons apparently not a matter of record, this instruction was not followed^{38,39} in other parts of the Navy, and indeed was ignored⁴² within the Bureau of Ships itself. Requests^{40,44,50} for Navy-wide consideration of the problem have either been dismissed briefly⁴¹ or have remained unanswered. Meanwhile, equipment is issued for use by the operating Navy, calibrated sometimes for one reference pressure⁴⁶, sometimes for the other⁴⁹.

THE PROBLEM

Of immediate and pressing concern is the fact that the use of two references for noise measurements in water leads to the following undesirable consequences:

(a) Reporting information about noise measurements, even in air, is handicapped by the necessity for continual and explicit statement of the reference pressure. The almost monotonous appearance of "0.0002 microbar" in a magazine like NOISE Control illustrates the cost of explicit statement of reference pressure.

(b) Communication of noise measurements between groups using the two reference pressures is inhibited. This is particularly true in oral discussion where it is time-consuming to give the reference pressure again and again: instead of straightforward quantitative statements, underwater comparisons are often based on the nominal noise of certain sea states.

(c) Use of two different reference pressures tends to prevent appreciation of any relation between sound in air and in water. Various Navy noise problems require consideration of the sound existing simultaneously in air and in water. For example, a sonar-equipped helicopter generates noise in air--how much of the noise passes into the water? A search for understanding of the physical principles invites comparison of the sound pressure levels in air and water. This comparison is much easier if the same reference pressure is employed in both instances.

(d) Negative levels are often encountered if 1 dyne/cm^2 is employed as a reference pressure for noise measurements. This is a particular disadvantage for field measurements, because for many equipments it may be necessary to add a positive meter reading to a negative attenuator setting. A negative sound level is not an intuitively obvious idea to the "man-on-the-ship." Moreover, statistical treatment (of considerable importance in these days of automatic data processing) becomes cumbersome when there are both positive and negative numbers.

It is worthy of emphasis that, so long as a single reference pressure is small enough to eliminate negative levels, the practical user of sound pressure levels is little concerned with the actual magnitude of the reference quantity; it is primarily the one who makes the theoretical calculations who needs to know.

It must be granted that 0.0002 dyne/cm^2 is a clumsy phrase. The number of occasions of need to employ the words, however, would be greatly reduced if this were the sole reference pressure in use for noise measurements.

The need for a single reference pressure is perhaps felt most keenly by those who compare underwater noise data from many sources. The need for uniformity can be satisfied by any single reference pressure: it is unfortunate that practical advantages of a single small reference pressure have not been exploited in some of the later compilations³⁹ of underwater noise. However, it is encouraging that, in some recent studies⁴³ of underwater noise control based on a systems approach, 0.0002 dyne/cm^2 was selected.

Interest in the use of 1 dyne/cm^2 as an underwater reference pressure stems from a proper desire to compare the output of an underwater sound projector with other sounds, and comparison is simplified by use of the same reference pressure in both cases. The same problem arises for loudspeakers in air, where 0.0002 dyne/cm^2 is being recommended⁴⁸ as the reference pressure; the same solution could be adopted for underwater sound projectors.

CONCLUSION

From the foregoing it appears that:

- (a) The same reference pressure should be used for sound pressure level, regardless of medium.
- (b) The reference pressure should be small enough to avoid negative levels.
- (c) 0.0002 dyne/cm^2 is now almost universally used as the reference pressure for sound pressure level measurements in air.
- (d) The general choice of 0.0002 dyne/cm^2 for use in water also is both justifiable and necessary in view of (a), (b), and (c).

EPILOGUE

The standard reference pressure for reporting airborne noise of aircraft, including helicopters, is 0.0002 dyne/cm^2 . Noise of a helicopter in air (its sound pressure level) needs to be compared with its noise and the ambient noise in water, so the same reference pressure should be used in all cases. Further, the underwater noises of other naval vehicles ought to be compared with the underwater ambient--and with each other--and by use of 0.0002 dyne/cm^2 consistently for all these different measurements comparisons can be made readily. Let us delay no longer in adopting this single reference pressure as a standard for water as well as for air.

APPENDIX A

Bibliography

This is a bibliography pertinent to the zero for noise measurements, with annotations relevant to the subject of standardization. It is not an exhaustive list, but rather indicative of thinking at a given period. Brief comments or quotations do not necessarily convey all the ideas of a given paper. The reader is invited to consult the original source material.

Complete texts of much of the unpublished material will be found in the copy of this memorandum to be filed in the library of the Navy Electronics Laboratory.

* * * * *

1. H. Barkhausen, "Ein Neuer Schallmesser für die Praxis," Zeit. tech. Physik 7:599-601 (1926); see Sci. Abs. A1470 (1927).

Barkhausen suggested steps to be taken toward international standardization of noise-measuring instruments, on the basis of a threshold of audibility taken, for example, as a sound energy density at 800 c/s of 1 erg/cm^2 . The "Wien" is suggested as a unit of loudness (2) [Lautstärke] and 1 erg/cm^2 was said to correspond to 3.584×10^6 Wiens. The statement of equivalence, however, suggests that the Wien was really a unit of sound pressure equal to 0.0003 dyne/cm^2 . (This is remarkably close to the modern determination of free-field threshold at 800 c/s of $3.3 \times 10^{-4} \text{ dyne/cm}^2$.) The need for a logarithmic scale was recognized and the "phon" was proposed as the unit thereof. The number of phons was equal to the logarithm on the base 2 of the number of Wiens. The noise of an automobile then reported as 14 to 16 phons looks reasonable today upon recognition of the fact that the original phon appears to have been a unit 6 times the size of the phon later adopted.

2. Rogers H. Galt, "Methods and Apparatus for Measuring the Noise Audiogram," J. Acoust. Soc. Am. 1:147-157 (1929).

An audiometer was used with an earphone having an offset cap that also admitted the ambient noise; the ambient noise level was by definition the amount in decibels by which the test sound had to be increased, over the threshold in a very quiet place, to be just audible in the presence of the ambient noise. The test sound was sometimes generated by a buzzer or phonograph record.

3. Harvey Fletcher, Speech and Hearing (D. Van Nostrand Company, 1929), pp. 102-107.

"If a meter were designed to give the proper importance to the various frequency components in the noise currents [in a telephone line], its reading would be an indication of the detrimental effects of the noise currents on the line. . . . Instruments [for measuring noise] have proved to be serviceable which measure the deafening effect of the noise upon the ear. For this reason, any instrument which has been designed for measuring the acuity of hearing can be used, with slight modifications, for measuring room noise. . . . In all these instruments the unit showing the degree of the deafening effect is the db. . . ."

4. W. J. Williams and R. G. McCurdy, "A Survey of Room Noise in Telephone Locations," J. Am. Inst. Elec. Engrs. 49:791-795 (1930).

"The sensitivity of the meter is such that a 1000-cycle tone with a pressure of about 0.014 dyne/cm² would give a reading of 0 db on the meter scale. This tone would be about 28 db above the threshold of audibility for the average ear."

5. E. E. Free, "Practical Methods of Noise Measurement," J. Acoust. Soc. Am. 2:18-29 (1930).

"There is much disagreement about units, definitions and methods of measuring sound intensities. . . . For noise measurements in decibels it is necessary, therefore, to adopt what might be called zero noise, at which the measurement scale may begin. . . . There is increasingly general agreement to adopt as this zero of the noise scale the faintest sound which the ear can hear at the frequency to which that organ is most sensitive. This minimum in physical units is approximately 7×10^{-16} watts per square centimeter."

6. Rogers H. Galt, "Results of Noise Surveys, Part I, Noise Out-of-Doors," J. Acoust. Soc. Am. 2:30-50 (1930).

This is one of a series of papers reporting noise surveys made both by instrumental means and by measurement of the "deafening effect." Calibration was largely accomplished by reliance on the ear. According to reference 16, by modern standards all readings were 7 db low.

7. T. G. Castner, E. Dietze, G. T. Stanton, R. S. Tucker, "Indicating Meter for Measurement and Analysis of Noise," Trans. Am. Inst. Elec. Engrs. 50:1041-1047 (1931) and "A New Noise Meter for Noise Analysis," Elec. Eng. 50:342-343 (1931).

"The sound meter is calibrated in terms of a 1000-cycle pressure of 0.001 dyne per sq. cm. in a free progressive wave. . . . For a 1000-cycle tone this reference level is somewhat above the minimum threshold of audibility of the average observer."

8. H. B. Marvin, "On the Loudness of Noise," J. Acoust. Soc. Am. 3: 388-392 (1932).

An improved audio noise meter and analyzer were described with the following modifications: "Reference frequency is 1000 cps and the reference sound pressure is .001 bar. The scale is calibrated in 'loudness units' which are numerically equal to decibels above the reference point. . . . The meter contains two weighting networks. . . . The curves were computed by interpolation from Kingsbury's data."

9. R. G. McCurdy, American Telephone and Telegraph Co., to H. Fletcher, Chairman of ASA Subcommittee on Noise Measurements, letter of about January 1933:

Although not specifically identified as such, this is apparently one of the memoranda mentioned in American Standard Z24.2-1936 and Z24.2-1944 as representing different points of view and as being "available for any who wish to study them." This letter states at the beginning that it was written in conference, particularly with W. N. Martin and A. F. Rose, in reference to a proposal by F. A. Firestone that a sound pressure be employed as the reference for acoustical measurements rather than an intensity.

"The use of a power basis for the scale for expressing acoustic intensities does not require that measurements should not be made of pressures. In the electrical communication field where this scale has been extensively applied, practically all transmission measurements are of voltage or current, with power derived from the circuit impedances at the points of measurement. The power basis for the scale does, however, call attention to proper consideration of the impedance conditions in the application of these measurements.

"In conclusion it should be pointed out that pressure ratios are not, literally speaking, expressed in decibels at all; the number of decibels resulting from the application of the formula $20 \log p_1/p_2$, where p_1 and p_2 are pressures, denotes logarithmically the ratio of the powers corresponding to the pressures. A statement such as "the pressure p_2 is 10 db above pressure p_1 " is an abbreviation for 'the power corresponding to the pressure p_1 .' Accordingly, if the proposal to use a value of pressure, 0.2 millibar, for example, were adopted, we would actually continue, just as with 10^{-16} watt base, to use a power base. The difference would be that with 0.2 millibar we would be using an unstated amount of power as the base, whereas, when 10^{-16} watt is used, the base is definite. Furthermore, unless the 0.2 millibar were definitely stated as being measured in a specified impedance, this unstated amount of power might be differently chosen by various workers, with the result that sound pressure levels might mean different things in different investigations. This, however, is precisely the situation we are trying to avoid. The combination of a pressure base, specification of the medium, and the use of the decibel scale all logically call for the use of a definite stated power base.

"The present arguments about the adoption of a scale in the acoustic field are similar to those which arose in connection with the adoption of the decibel scale in telephony. In both fields it is considered that the scale and the zero point should be fundamentally based on power."

10. W. A. Osbon and K. A. Oplinger, "A New Portable Meter for Noise Measurement and Analysis," J. Acoust. Soc. Am. 5:39-45 (1933).

"For making loudness measurements there is provided a frequency weighting network which gives the instrument a response characteristic corresponding to the Kingsbury equal loudness contour passing through a point 40 db above 0.001 dyne per sq. cm. at 1000 cycles."

11. American Standards Association Committee on Acoustical Measurement and Terminology, "Proposed Standards for Noise Measurement," J. Acoust. Soc. Am. 5:109-111 (1933).

"The sound intensity of a sound field in a specified direction at a point is the sound energy transmitted per unit of time. . . . There was considerable discussion in the committee as to what should be chosen for the reference or zero level. . . . Since that time [of our first report] there has been considerable discussion as to whether the intensity level scale which was originally proposed or a pressure level scale using one bar as the reference level should be adopted. Several memoranda were written upon the two points of view which are available for any who wish to study them."

These proposals later became American Tentative Standards for Noise Measurement Z24.2-1936.

12. E. J. Abbott, "Scales for Sound Measurements Used in Machinery Noise Reduction," J. Acoust. Soc. Am. 6:137-149 (1935).

"The fundamental difficulty seems to be that there are at least eight scales in general use for expressing the magnitude of a sound, and five of them are decibel scales. It is all too common practice to simply label the ordinate "db" and leave the reader to guess just what was measured. . . . As far as the author is aware, this completes the list of sound powers and energies which have been defined for an interference field, and it is obvious that none of these quantities was measured by our meter. . . . As far as the author can see, any attempt to think through a scheme of expressing sound pressure measurements in an interference field in terms of real power leads either to scientific inconsistencies or practical absurdities or both. . . . Thus the workers at our laboratory conclude it is best. . . to express data directly in sound pressure levels. . . . Nearly everyone tried to avoid using decibels at first, but the unit has been almost universally adopted on account of its practical conveniences. . . . In view of these practical considerations. . . much confusion will be eliminated if these three scales [sound pressure level, weighted sound pressure level, and loudness level] are used, and if the scale employed for every set of data is definitely labelled on the graph. . . . It has been suggested that. . . convenience of interpretation would be improved

by using a reference level of 0.001 bars, or 0.01 bars. . . . These references have been considered by standardization committees and 0.0002 bars has been adopted."

13. American Tentative Standards for Noise Measurements Z24.2-1936
[Reproduced in J. Acoust. Soc. Am. 8:143-146 (1936)].

Intensity is defined as "sound energy transmitted per unit time in the specified direction through a unit area normal to this direction The reference intensity for intensity level comparisons shall be 10^{-16} watts per square centimeter." It is pointed out that in a free progressive wave in air under certain conditions this intensity corresponds to a sound pressure of 0.000204 dyne per square centimeter. Sound pressure level and velocity level are also defined and in each instance the unit is given simply as the decibel; the respective reference quantities are named as 0.0002 dyne per square centimeter and 0.000005 centimeter per second; there is no indication that these reference quantities are limited to use in air or that they be changed for varying conditions of the air or for another medium.

14. American Tentative Standards for Sound Level Meters for Measurement of Noise and Other Sounds Z24.3-1936 [reproduced in J. Acoust. Soc. Am. 8:147-152 (1936)].

"The reference point of the decibel scale incorporated in sound level meters shall be reference sound intensity (10^{-16} watts per square centimeter) at 1000 cycles in a free progressive wave."

15. Extract from Translation of Minutes of International Conference on Acoustics Paris June 30 - July 3, 1937

"The Sub-Committee No. 2 of the International Acoustics Conference was appointed, under the Chairmanship of Dr. Harvey Fletcher (USA), to consider questions relating to Fundamental Units and Methods of Measurements for Acoustics - with particular reference to measurements of Noise.

"The Sub-Committee agreed that, for the purpose of defining the units and scales required for measurements of noise, the term Sound Intensity in progressive waves shall be defined as 'The rate of flow of sound energy per unit of area (sq. cm.) normal to the direction of propagation.' This definition, however, applying only to progressive waves, was considered to be inadequate for more general use and the question of the general definition of 'Sound Intensity' was referred to Sub-Committee No. 1.

"The Sub-Committee further agreed that the 'Reference Sound' to be used as the basis from which units and a scale for measurements of noise would be derived shall be characterised as follows:

- "1) The sound shall be a sinusoidal, plane, progressive wave having a frequency of 1000 cycles per second
- "2) The zero of reference shall be taken, in round figures, either as an intensity of 10^{-16} Watts per sq. cm. or as a sound pressure of 2×10^{-4} dynes per sq. cm.^x
- "3) In either case the scale of intensity or of pressure shall be measured in decibels with respect to this zero of reference.

"The Sub-Committee also agreed that the unit to be used for measurements of noise shall be termed the 'phon', the measurement being carried out as follows: . . .

^xThe effective value P of the sound pressure corresponding to the intensity of 10^{-16} Watts per sq. cm. is, more accurately, given by the formula:

$$P = 0.000207 \sqrt{\frac{H}{76}} \sqrt{\frac{273}{T}}$$

where P is expressed in dynes per sq. cm., H is the height of the barometer in cms and T is the absolute temperature."

The above extract was kindly furnished by R. A. Dadson, 31 July 1959. The 1937 meeting was held under the auspices of the International Federation of the National Standardizing Associations (ISA). See summary in Akust. Zeits. 2:215 (1937). German implementation of the Paris decision was based on a reference pressure of 2×10^{-4} μ bar [see Akust. Zeits. 3:59 (1938)]; this required change from the earlier German standard of 0.000313 dyne/cm² [see Akust. Zeits. 3:320 (1938)].

16. J. M. Barstow, "Sound Measurement Objectives and Sound Level Meter Performance," J. Acoust. Soc. Am. 12:150-166 (1940).

Various reference points employed in the early sound level meters are reviewed briefly as an introduction to a report of extensive experimental work on the actual behavior of sound level meters.

17. Paul Huber and John M. Whitmore, "Sound Level Meters from the User's Viewpoint," J. Acoust. Soc. Am. 12:167-172 (1940).

"No manufacturer of noise meters in this country, at the present time, is putting any limit at all on the accuracy of his product. He is issuing no warning as to the conditions under which that instrument will exceed any tolerance, even the plus or minus 25 db of the ASA."

18. Daniel F. Hoth, "Room Noise Spectra at Subscribers' Telephone Locations," J. Acoust. Soc. Am. 12:499-504 (1941).

". . . the average room noise spectrum in terms of the sound pressure per cycle in db versus one dyne per square centimeter." One wonders, incidentally, if the quantity involved was really (pressure squared) per cps.

19. "Runs made 4 - 10 April 1941", Massachusetts Institute of Technology, Division of Industrial Cooperation [contract] 5985, Report I, n. d.

A report of underwater ship noise measurements. Graphs are marked "Sound pressure level in decibels" and in later reports of this series a pressure scale is also added that makes it clear that the reference pressure was 0.0002 dyne/cm^2 .

20. Messgerät für DIN-Lautstärken DIN 5045, April 1942.

This was reproduced in Akust. Zeits. 7:156-158 (1942), and preliminary versions in Akust. Zeits. 2:54-55 (1937) and 5:305-307 (1940). The standard is in many respects similar to American Standard Z24.3-1936 except that calibration was based on a free progressive wave and a sound pressure of 2×10^{-4} microbar; the idea of random-incidence calibration did not appear.

21. V. O. Knudsen, R. S. Alford and J. W. Emling, "Survey of Underwater Sound" Report No. 1, NDRC Div 6 Rep 6.1-729, 26 February 1943, and three succeeding reports with the same title in part.

22. American Standard Sound Level Meters for Measurement of Noise and Other Sounds, Z24.3 - 1944.

In contrast with Z24.3 - 1936 in which a reference intensity was specified, in this revision:

"2.5.1 The reference point of the decibel scale incorporated in sound level meters shall be the reference sound pressure of $0.0002 \text{ dynes per square centimeter at } 1000 \text{ cycles.}$ "

23. E. Dietze, "Response and Efficiency Definitions for Projectors and Hydrophones," OSRD Report Section No. 6.1 - sr1130 on Project NS-1823, dated 1 July 1944.

Copies of this report seem to have been destroyed. It appears, however, that a reference pressure of 0.0002 dyne/cm^2 was proposed for the calibration of hydrophones and underwater projectors.

24. John T. Tate, Chief NDRC Div 6, to G. P. Harnwell, UCDWR, letter dated 3 July 1944.

This is a notice of a meeting to be held 19 July 1944.

25. Report of Conference on Underwater Sound Projectors held in Washington 19 July 1944.

This is described as a third meeting of the Hydrophone Advisory Committee. "A meeting of the subject committee was called to reach agreement on definitions of response and efficiency of underwater sound

projectors used either for transmitting or receiving, based on recommendations given in reference [23 of the present list]. . . . The Bureau of Ships had requested the present meeting. . . . agreements were reached [on]. . . . the transmitting response of a projector. . . in terms of the pressure at 1 meter distance on the acoustic axis in decibels vs reference pressure (1.0 dyne/cm^2) for 1 watt available power."

26. E. Dietze, "Measurement of Projector and Hydrophone Performance-- Definitions and Terms," Underwater Sound Reference Laboratories, NDRC Section 6.1-sr 1130-1833, 19 September 1944.

"This report, in accordance with the wishes of the conference [see reference 25] discusses the definitions and terms agreed upon."

27. E. H. Colpitts, Chief NDRC Section 6.1, to G. P. Harnwell, Director UCDCWR, letter of 9 October 1944.

"There has been sent to you a copy of the report by the Underwater Sound Reference Laboratories entitled, 'Measurement of Projector and Hydrophone Performance - Definitions and Terms,' report No. 6.1-sr 1130-1833. This is a very important report in that for the first time general agreement has been obtained regarding reference levels and units to be used in the underwater sound field. I am told that in this respect the underwater sound field is considerably ahead of the sound-in-air field.

"In the preparation of our final summary technical volumes, we have a good opportunity to initiate on a rather comprehensive scale the introduction of these new units. I shall appreciate it if you will give instructions to all of your men concerned with the writing of reports to follow these definitions as closely as is practicable.

"I should point out that one of the important agreements reached is that the reference pressure shall be set at 1 dyne/cm^2 . This action, upon which unanimous agreement was obtained rescinds earlier action in which $0.0002 \text{ dynes/cm}^2$ was set as a reference level. . . ."

28. T. Keith Glennan, Director CUDWR, to E. H. Colpitts, Chief NDRC Section Div. 6.1, letter of 16 October 1944.

"This letter is in reply to yours of October 9, 1944. . . . We are in entire agreement with all of these definitions and we shall use them in all future reports of our calibrations [of projectors and hydrophones].

"The tone of your letter indicates that in addition to the use of the reference pressure, $1 \text{ dyne per square centimeter}$, for hydrophone and projector measurements it should also be used for expressing all sound measurements. It seems to me that such a change at this time would result in a great deal of confusion in the field. Substantially all of the background measurements and ship sound measurements which have been reported by NDRC groups have been expressed using the base $.0002 \text{ dynes per square centimeter}$ as you know. The Naval operating forces have come to recognize levels expressed in these terms and this particularly

applies to the submarine forces who are using 40 OAY Sound Measuring Equipments in their noise reduction program. I have talked with Comdr. Colledge on this point and find that he has received no request from the Coordinator's Office to make any change in the reference on which his measurements will be based and he feels strongly that any change at this time would seriously impede the efforts of his department.

"In view of these considerations, I recommend that in all publications and communications primarily designed for the Naval operating forces the old scales be featured. Possibly the new scale might be included in addition although it is my personal view that for the present this will only cause confusion. . . ."

29. R. W. Young, UCDWR Listening Section to G. P. Harnwell, memo of 19 October 1944.

"The announced function of the conference was 'to reach agreement on definitions and response and efficiency of underwater projectors:' I find no indication in Reference [here, 26] that the conference considered acoustical measurements other than those announced. Therefore it is not clear on what grounds we are being told to use 1 dyne/cm² as a reference pressure for such things as the measurement of ship sound.

"3. At least 80% (my estimate) of underwater measurements of sound pressure level made in this country on ship sound and the like during the past three years have referred to 0.0002 dyne/cm². . . .

"6. In time of war it is necessary to train large numbers of people for work new to them.

(a) A sound level meter having both positive and negative readings is not conducive to error-free use by the uninitiated.

(b) Since the reference pressure in air is 0.0002 dyne/cm², to retain the same reference for underwater use might simplify the 'carry-over' for persons trained in air measurements. . . .

"Two courses of action seem appropriate:. . . . Request the formation of a committee to review the entire subject and as a result of its calm deliberation and polling of opinions to recommend appropriate standards for future underwater use."

30. R. J. Christensen, UCDWR Echo-Ranging Section, to G. P. Harnwell, memo of 20 October 1944.

"My impression is that further consideration of the problem of reference units is in order. Let's adopt units consistent with the use to which the data are to be put or else have the Navy adopt a new set."

31. G. P. Harnwell, Director UCDWR, to E. H. Colpitts, letter of 21 October 1944.

"A proposal which appears to me to have merit is that a conference be arranged to consider the many questions that are posed to acoustic engineers by your letter of October 9, with a view to resolving those in the most satisfactory manner possible for our immediate purposes, with particular reference to the whole field of noise level measurements not specifically covered by the USRL report but intimately associated with the establishment of any system of standards and units."

32. E. H. Colpitts, Chief NDRC Section 6.1 to G. P. Harnwell, Director UCDWR, letter of 8 November 1944.

"We have discussed this matter with a large number of people in our own group and in the Navy, and have found the following:

- a. The Navy plans to adopt 1 dyne/cm^2 for all calibrations, specifications, and sound level measurements.
- b. The British have been using 1 dyne/cm^2 as a reference level for many years.
- c. The majority of NDRC laboratories already use, or plan to use in the near future, 1 dyne/cm^2 as the reference level for both calibrations and sound level measurements.

"We have decided, therefore, as a general policy, to ask all Division 6 laboratories to use 1 dyne/cm^2 as a reference level in any reports. . . ."

It is hard to understand how these statements could have been made, in view of the just preceding correspondence. The proposal that a conference be called to study the specific problem of standardization was completely ignored, as was also the evidence that one part of the Navy had no plan to adopt 1 dyne/cm^2 as the reference pressure for ship noise measurements (and still does not in 1960). Moreover, most of those in the NDRC laboratories principally concerned with ship noise measurement continued to use 0.0002 dyne/cm^2 for their field measurements.

33. "Principles of Underwater Sound," NDRC Summary Technical Reports, Div. 6, Vol. 7 (1946) Part I, page 2.

After two definitions of intensity are given, "For many practical purposes a third definition of sound intensity may be used,

$$I = p^2 \text{ (dynes}^2\text{/cm}^4\text{)}.$$

This unit is convenient because, while energy flow and energy are difficult to measure, the sound pressure p is easily measured. This definition of intensity will be used in this book. . . . Two units of pressure are in common use. These are 1 dyne/cm^2 and 0.0002 dyne/cm^2 Both units have been used in dealing with underwater sound but the dyne/cm^2 is preferred by the Navy." The definition of intensity

there adopted helps little in clarifying the physical ideas in the minds of the unsuspecting who also refer to other sources of acoustical information in which intensity is differently defined.

34. Minutes of joint meeting of American Standards Association Subcommittees Z24A (Terminology) and Z24G (Underwater Sound) on May 7, 1947 prepared by M. S. Richardson, Case 36623-101.

During the course of this not always quiet 6-hour meeting, "several observations were made as to the use of levels and references:

(1) "The number of people who use acoustics and acoustical information is large compared to the number who practice acoustics professionally.

(2) "References are important to the instrument manufacturer and the man who may make theoretical use of observations but are relatively unimportant to the man who uses a single measuring instrument as a means to a non-acoustical end.

(3) "In general, levels are not used during the course of theoretical work.

(4) "The db, and levels, are not widely used in vibration studies.

(5) "Vibration work has been hampered, however, by the lack of agreement as to units.

(6) "The past 20 years has shown the utility of pressure and the lessening use of intensity."

A motion was passed 17 to 2: "It is recommended that a single sound reference pressure (stress) be adopted for use in all media." Later this was "reconsidered" by vote 13 to 6. The basis on which agreement was finally reached was simply that "the reference pressure shall be explicitly stated." It was from this action, as later incorporated in 1.325 of Z24.1-1951, that the reference pressure is written so frequently in graphs and tables.

These subcommittees had devoted a great deal of time to the same topic at their meetings in Chicago in November 1946, and several extensive documents had been circulated during the interim.

35. L. E. Kinsler and A. R. Frey, Fundamentals of Acoustics (Wiley, 1950), p. 136, 435.

"In underwater acoustics the standard of intensity is that corresponding to an rms pressure of 1 dyne/cm². . . .

"5.9 Decibel Intensity Scale. Intensity levels can also be expressed in terms of pressures by

$$n = 20 \log (P/P_0)$$

where P_0 is the reference pressure A reference pressure of 1 dyne/cm² is equivalent to a plane wave reference intensity of 6.75×10^{-6} erg/cm² sec in fresh water and 0.0241 erg/cm² sec in air, and a reference pressure of 0.0002 dyne/cm² is for all practical purposes identical with 10^{-9} erg/cm² sec in air. . . .

"15.3 Intensity of Sound in Sea Water Since the standard characteristic impedance of sea water is about 3700 times as great as that of air, i. e. 153,500/41.5, the intensity corresponding to this pressure [of 0.0002 dyne/cm²] is only $10^{-16}/3700 = 2.7 \times 10^{-20}$ watt/cm² in air....The former intensity is far below the threshold of audibility, and consequently the use of 0.0002 dyne/cm² as a reference pressure level for sound in sea water is to be deprecated.

. . . . The arbitrary value of 1 dyne/cm² . . . corresponds to an intensity of 6.5×10^{-13} watt /cm² which is typical of the intensities of the ambient noise background in the sea."

36. Bureau of Ships Instruction 3980.1 (originally 3985.1) "Supplementary Definitions for Underwater Acoustical Terminology" 15 August 1952.

"1-326 Reference Sound Pressure

"The recommended rms reference pressure for expressing both air and underwater sound pressure levels is 2×10^{-4} microbar, except that in the calibration of transducers the reference pressure may be 1 microbar.

"Note: The reference pressure should be stated explicitly in all tables, figures, and at pertinent points in the text."

These definitions were developed by a subcommittee of the BUSHIPS Noise and Shock panel, consisting of 3 representatives from BUSHIPS, and one each from DTMB, USNUSL, NEE, NEL.

37. Chief, BUSHIPS to Distribution List Ser 847-313 letter of 30 November 1953.

"Bureau of Ships Laboratories and Contractors are requested to take cognizance of the definitions given in enclosure (1) and references (a) and (b) [American Standard Acoustical Terminology Z24.1-1951 and Bureau of Ships Instruction 3985.1] and to adopt them in all reports and presentations submitted to the Bureau of Ships."

38. "Minutes of the Fourth Conference of the Acoustics of the Medium Program," held at Applied Physics Laboratory, University of Washington, Seattle, 15 September 1954.

"Agenda Item No. 5: Discussion of the use of standard definitions and units for the reporting of work on this program.

"In opening the discussion, D. C. Whitmarsh of ORL submitted for consideration BUSHIPS Instruction 3985.1, 'Definitions for Underwater Acoustical Terminology.' However, it was the opinion of the conferees that the BUSHIPS document had only limited applicability to the ordnance field. After a lengthy discussion, it was decided that the units to be used for reporting on the experimental programs and the literature search on the Acoustics of the Medium program would be as follows:

"English units of measure would be used for all quantities with the exception of acoustical pressure levels. In particular, it was agreed that horizontal range should be measured in yards and depth in feet, with the unit of pressure being the dyne per square centimeter. The reference level for acoustic pressure when utilizing a decibel scale received considerable attention. Although all of the conferees agreed that a reference level of one dyne per square centimeter is the most reasonable level to use, it was originally proposed that we maintain the BUSHIPS standard of 0.0002 dynes per square centimeter for noise sources. However, after a most persuasive argument from Dr. R. J. Urick of NRL, it was agreed that this program would not perpetuate the use of the BUSHIPS reference level, but would instead utilize one dyne per square centimeter as a reference level for all acoustic measurements."

The "most persuasive argument" is unfortunately not recorded.

39. R. J. Urick and A. W. Pryce, "A Summary of Underwater Acoustic Data, Part I, Introduction," ONR Report, July 1953, p. 16.

"At the present time one comprehensive survey of existing data is provided by the NDRC summaries of wartime research and development. Although the volumes are of unquestionable value. . . . the data tends to be wrapped in lengthy and often academic discussion which makes the volumes difficult to use as working references. . . .

"The source level of a projector or target is the intensity of the sound emitted by the projector or target at a distance of 1 yard from its effective acoustic center, expressed as spectrum level in db relative to the intensity equivalent of a pressure of 1 dyne/cm² in a 1-cps band for a wideband source and in db about the same reference level for a single frequency source."

"Part VI, Source Level," May 1955, p. 1.

"In this report we shall adopt 1 dyne per cm² as the reference pressure and 1 yard as the reference distance in conformity with the units adopted in this series of reports (See Part I Introduction)."

40. BUSHIPS ltr to ONR S40/1(371) Ser 371-432 of 19 July 1955.

The suggestion was made that ONR explore standardization. "Comparison of underwater noise data would be greatly facilitated and misunderstandings minimized if the acoustic reference values employed by all reporting activities were identical. . . . Exploration of the practicability of standardizing on three quantities is recommended; namely, the reference sound pressure, reference distance and filter bandwidths."

41. ONR to BUSHIPS, ONR:411:AWP:mfh serial 23785 of 19 October 1955.

In response to reference 40,

"In general, it is believed that the probability of obtaining complete standardization in this field is remote. Past experience indicates that much valuable effort can be expended in attempts to obtain this objective with little success. Such expenditures of effort are particularly regrettable in that the choice of units is largely arbitrary. In general, it appears that the arbitrary nature of the units tends to make individual activities more, rather than less, tenacious to their individual preference."

42. BUSHIPS to Georgia Tech Research Institute, Nobs 55188(530) Ser 530-1650 letter of 1 December 1955.

In the course of a conference by J. F. Kinny, Capt. A. A. Wellings, and W. B. White "it was pointed out that the British has standardized on referring all acoustic measurements and data to 1 dyne per square CM. . . . In order to make it easier to compare acoustic data directly . . . it is requested that in the future all acoustic data be reported using 1 Microbar as the reference level."

43. Noise Control Group, Committee on Undersea Warfare, National Research Council "Submarine Noise Control," Serial NRC:CUW:0242, 6 December 1957.

44. NEL to BUSHIPS, file S81 Serial 2082-09 letter of 30 April 1958.

This 10-page letter and enclosures commenting on standards for underwater noise measurements ended with: "These problems are not new and it seems unlikely that they will be solved solely by directive. There must be a meeting of minds. It is proposed, therefore, that representatives of those in the USA who are affected be invited to explain their needs to each other, to understand each others needs, and by collective group action to formulate a standard procedure that will best meet the collective needs. . . ." It appears that the material was never transmitted to the NATO conference for which it was prepared, nor was the letter ever acknowledged.

45. C. B. Officer, Introduction to the Theory of Sound Transmission (McGraw-Hill, 1958) p. 28.

"Practically all measurements of intensity from underwater sound transmission measurements are quoted in decibels. The decibel is based on the logarithmic scale to the base 10, and the intensity on the decibel scale is equal to ten times. . . .

"Various reference levels are used in stating intensities in decibels. The common practice in underwater sound transmission is to refer intensities to a pressure level of 1 dyne/cm² under the assumption of plane waves and the relation between intensity and pressure. The reason for using a reference pressure level rather than an intensity level is that in most experiments the receiver (hydrophone) is sensitive to pressure. . . . Other reference levels that are used are a pressure level of 0.0002 dyne/cm² . . . and intensity levels of 1 watt/cm² and 1 watt/yd²." The phrase "measurement of intensity" tends to perpetuate the mistaken idea that intensity is actually measured.

46. Sound Measuring Set Mark 1 Mod 1 and Sound Measuring Set Mark 2 Mod 0 Description, operation and maintenance, OP2114, 10 February 1958.

"[The sound measuring set] is calibrated so that the underwater noise intensity may be read directly in db spectrum (db versus 0.0002 dyne per square centimeter per cycle). . . . (In terms of the newer reference level of 1 dyne per square centimeter a conversion factor of -74 db applied to measurements made using the old reference.)"

47. "Expression of the physical and subjective magnitudes of sound or noise" ISO/R131-1959.

"It is recommended that data on the physical magnitude of sound or noise should be expressed by a statement of the sound pressure level (see below) or in terms of the sound intensity level or sound power level. . . . It is recommended that, for sound in air, the value 2×10^{-4} dyne/cm², (2×10^{-5} N/m²) r.m.s., be universally adopted as the reference pressure.

NOTE. It should be noted that, when measurements are made in terms of the sound pressure level, an expression in terms of the sound intensity level or sound power level can only be derived if the sound field concerned is of an appropriate and well defined type."

(The above text is from a 1959 draft.)

48. American Standards Committee document S1/15 "Proposed American Standard Recommended Practices for Loudspeaker Testing," 28 March 1958, and Institute of Radio Engineers committee document 50 IRE 30.PSI "Proposed American Recommended Practices for Loudspeaker Testing," 24 June 1959.

"The recommended reference quantities are 0.0002 microbar (dyne per square centimeter) for pressure and 0.001 watt for power."

49. Technical Manual for Sound Measuring Set AN/SQM-1, Contract Nobsr75394 approved by BUSHIPS 20 August 1959. (NAVSHIPS 93,417).

"The sound measuring set measures the equivalent plane wave pressure level of sonar self noise at a given bearing, expressed in decibels with respect to 1 microbar. . . over a range -58 to 0 db// μ bar."

50. NEL to BUSHIPS file 4121 Serial 2082-14 letter of 12 November 1959.

"The purpose of this letter is to request that the American Standards Association be asked to develop, under its safeguards for broad representation, a standard for the reference quantities for underwater noise measurements (a standard not necessarily the same as for calibration of transducers) with particular consideration of the Navy's needs."